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Effects of Irrigation on Accumulation of Soil and Symbiotically Fixed N by Soybean Grown on a Norfolk Loamy Sand[1]

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ABSTRACT

In the southeastern Coastal Plain, soybean [*Glycine max* (L.) Merr.] is normally grown on soils that are often exposed to drought and leaching rains as well as being low in available N. A field study was conducted to evaluate the impact of water management on accumulation of soil and symbiotically fixed N by soybean grown on these type soils. Nodulating and nonnodulating isolines of 'Lee' cultivar soybean were grown under irrigated and nonirrigated conditions in 1979 and 1980 on a Norfolk loamy sand (fine-loamy, mixed, mesic Typic Paleudults). A period of excessive rainfall occurred in 1979, while a major drought occurred in 1980. Irrigated treatments had lower soil-NO_3^- concentrations in the Ap horizon than nonirrigated treatments during 1979, but there was no effect of irrigation on soil NO_3^- in 1980. Dinitrogen fixation, as estimated by the difference in N accumulation between nodulating and nonnodulating isolines, accounted for 76 to 91% of total plant N in the irrigated plots and 55 to 60% in the nonirrigated plots. Estimates of total plant N fixed exceeded 1100 mg/plant for the irrigated plots in 1979 and 1980. Maximum N accumulation for the nodulating isoline occurred in the nonirrigated plots in 1979 and in the irrigated plots in 1980. However, the nonnodulating isoline had maximum accumulations of both N and dry matter in the nonirrigated treatments in both 1979 and 1980. The number of nodules/plant and the C_2H_2-reducing activity were significantly higher in the irrigated plots during the pod growth stages in 1980. Irrigation did not significantly affect seed yield of nodulating Lee soybean in 1979, but did result in a twofold increase in 1980. The effects of irrigation on the Lee nonnodulating isoline resulted in a positive yield response in 1980, but a negative response in 1979. These findings show that a major portion of the N-requirement for soybean in the southeastern Coastal Plain is met by fixation and that the relative importance of fixed N may vary substantially with rainfall patterns and irrigation.

***Additional index words:* *Glycine max*, N-fixation, C_2H_2 reduction, Biomass production.**

SIGNIFICANT amounts of either soil or symbiotically fixed N are essential for successful soybean [*Glycine max* (L.) Merr.] production. Many workers have reported that soybean accumulate >300 kg N/ha (Henderson and Kamprath, 1970; Bezdicek et al., 1978; Nelson and Weaver, 1980; Hunt et al., 1981). However, the values for total plant N provided by fixation varies in the literature. Hardy and Havelka (1976) stated that fixation contributed only 25% of the N requirement for indeterminate soybean. Bezdicek et al. (1978) concluded that fixation, as measured by plant uptake, may contribute more than 70% of the plant N requirements. They noted that total N fixed, based on the acetylene-reduction (C_2H_2) method, was less than half of the value determined by plant N uptake. Nelson and Weaver (1980) reported that 86% of the total N accumulated during the pod growth stage was attributed to fixation and that neither the amount of dry matter accumulated nor the N distribution within 'Lee' soybean was affected by plant densities between 48 500 and 194 000 plants/ha. Weber (1966b) reported that 1) fixation may be considerably lower when moisture is limited than when moisture is adequate, and 2) the amount of N fixed may range from 1 to 74%. He and other authors have also shown N fixation to vary with the availability of soil N (Weber, 1966b; Bezdicek et al., 1974; Lawn and Brun, 1974).

The soils of the southeastern Coastal Plain are generally very low in soil N and soil organic matter. The high annual rainfall and/or irrigation in this region causes loss of applied and residual N by leaching and denitrification. Under these conditions, fixation may become the primary source of N for soybean, and the residual N may become important to subsequent crops.

Soybean isolines, genetically similar except for their ability or inability to nodulate, have been used as tools to measure N-fixation and residual N (Sears and Lynch, 1951; Weber, 1966a, 1966b; Nelson and Weaver, 1980). However, the use of soybean isolines to measure the effect of irrigation and seasonal rainfall patterns on N accumulation of determinate soybean in the southeast has not been documented. The objective of this study was to assess the impact of water management on accumulation of both soil- and symbiotically-fixed N in nodulating and non-nodulating determinate soybean under irrigated and nonirrigated conditions on a soil of the southeastern Coastal Plain.

MATERIALS AND METHODS

A completely randomized block design with three and four replications was used in 1979 and 1980, respectively, on a Norfolk loamy sand (fine-loamy, mixed, mesic, Typic Paleudults) with irrigation as the main plot treatment. Plots had six, 5.4-m rows on 96-cm spacing with the first and sixth rows as border rows. Fertilizer application consisted of 17.4 kg P/ha and 33.5 kg K/ha in 1979 and 19.2 kg P/ha and 37 kg K/ha with 892 kg/ha of dolomitic limestone in 1980.

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Treflan[3] (trifluralin, *ααα*-trifluoro-2,6-dinitro-*N*,*N*-dipropyl-*p*-toluidine) was applied at the rate of 0.3 L/ha and incorporated by disking prior to planting. A nodulating and non-nodulating soybean isoline, 'Lee', was planted to a depth of 2.5 cm on 24 May 1979 and 27 May 1980. Stand counts showed densities of 20 plants/m^2 in 1979 and 26 plants/m^2 in 1980. The lower stand count in 1979 was attributed to equipment malfunction during planting operations. Irrigation water was applied through trickle tubing to maintain soil matric potential above −25 kPa at the 60-cm depth. Soil matric potential was monitored with vacuum gauge tensiometers at 30-, 60-, 90-, 120-, and 150-cm depths. Rainfall was monitored by an automated rain gauge. Irrigation was initiated on 14 June 1979 and 13 June 1980 with 244 mm of water being applied in 1979 and 671 mm in 1980.

Whole-plant samples (leaves, stems, petioles, and pods) were collected from approximately 30 cm of row in individual plots 38, 73, 90, and 122 days after planting in 1979 and 49, 58, 93, and 113 days after planting in 1980. These dates correspond with the vegetative, flowering (R2), early (R4), and late (R6) pod development growth stages, respectively (Fehr et al., 1971). Sampled plants were rinsed with demineralized water, dried at 70° C, weighed, ground to pass a 0.5 mm screen, digested by a block digestor, and analyzed for total Kjeldahl N with a Technicon Auto Analyzer using industrial method 334-74 W/B (Technicon Industrial Systems, 1977). Root samples were extracted from 25 cm of row to a 30-cm depth and assayed for N-fixation in 1980 by the C_2H_2 reduction method (Hardy et al., 1968). Specific C_2H_2-reducing activity was calculated from nodules manually removed from the roots after counting and weighing. The indigenous rhizobia infecting the roots were identified as belonging to U.S. Department of Agriculture serogroup I1b 110, 3I1b 122, and N.C. 1004 by the short agglutination test (Stowers and Elkan, 1980). No rhizobial inoculant was added. Yields were taken from 5 m of the middle four rows of individual plots. Nitrate content of the Ap, E, and B2t soil horizons were determined during late pod fill by the specific ion electrode method. Data were analyzed using analysis of variance and least significant difference as outlined by Steel and Torrie (1960).

RESULTS AND DISCUSSION

Environmental Conditions

Seasonal precipitation patterns were distinctly different with periods of drought occurring more frequently in 1980 than 1979 (Fig. 1). Precipitation totaling 185, 83, and 454 mm in 1979 and 137, 58, and 220 mm in 1980 fell during the vegetative, flowering, and pod growth stages, respectively. Drought conditions in 1980 necessitated a higher application of irrigation water as compared to 1979. Water extracted from the lower profile in 1979 helped reduce plant water stress in the nonirrigated plots; soil matric potential at the 120-cm depth did not exceed −40 kPa. Soil matric potential in the nonirrigated treatments at the 120-cm depth in 1980 exceeded −60 kPa and −80 kPa during the flowering and early pod growth stages, respectively. Pressure chamber measurements of xylem pressure potential (unpublished data) showed that the nonirrigated plants were stressed during these growth stages in 1980. Rainfall was adequate during late pod fill in 1980 to prevent plant water stress in the nonirrigated plots. During this period, soil matric potential did not exceed −40 kPa at the 120-cm depth.

In 1979 the NO_3^- concentration of the Ap horizon was decreased by irrigation (33.9 μM/kg ± 10%[4] and 97.3 μM/kg ± 9% for irrigated and nonirrigated plots, respectively). The NO_3^- concentration of the E or B2t horizons (44.0 μM/kg ± 35% and 23.7 μM/kg ± 37%, respectively) was not affected by irrigation in 1979. The higher soil water content of the irrigated plots as compared to the nonirrigated plots probably accelerated NO_3^- leaching and denitrification during periods of rainfall. Nitrate concentrations of the Ap, E, and B2t horizons were 57.4 μM/kg ± 23%, 38.7 μM/kg ± 12%, and 46.0 μM/kg ± 22% in 1980, respectively. Irrigation had no effect on the NO_3^- concentration in 1980.

Nitrogen Accumulation

Maximum N accumulation of the nodulating isoline was not significantly different under irrigated or nonirrigated conditions (Table 1). Maximum N accumulations were 1240 and 1570 mg/plant in 1979 and 1473 and 1400 mg/plant in 1980 for irrigated and nonirrigated conditions, respectively. However, during the

[3] Mention of trademark, proprietary product, or vendor does not constitute a guarantee or warranty for the product by the USDA or the S.C. Agric. Exp. Stn., and does not imply its approval to the exclusion of other products or vendors that may also be suitable.

[4] Data are presented as mean values ± coefficient of variation.

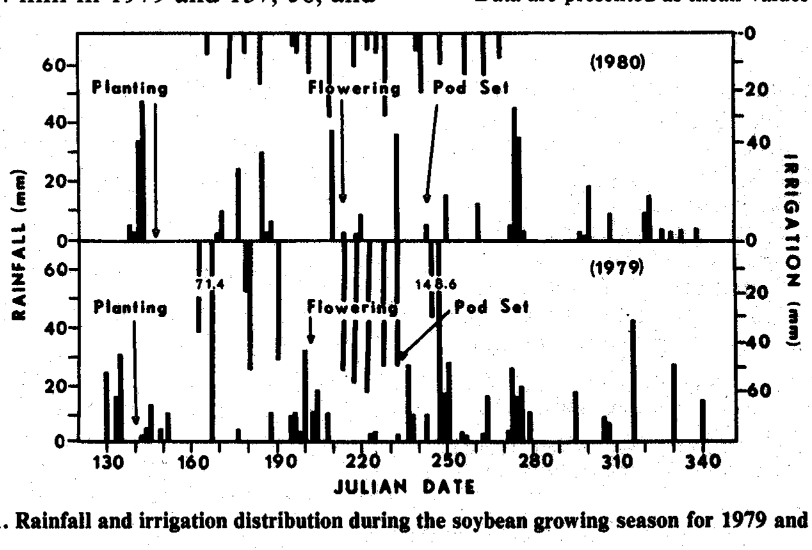

Fig. 1. Rainfall and irrigation distribution during the soybean growing season for 1979 and 1980.

1980 late pod fill stage (113 days after planting, DAP), the nonirrigated, nodulating isoline had a significantly lower N content than the irrigated plants. Total plant N decreased at the rate of 8 and 26 mg N/plant/day under irrigated and nonirrigated conditions, respectively, between 93 and 113 DAP. The higher retrogression of plant N during this period under nonirrigated conditions was due to rapid leaf abscission and lower seed content. The N content of fallen leaves was not determined. The plants in the nonirrigated plots also had numerically lower dry matter than the irrigated plants during the 1980 late pod fill stage (Table 2).

Maximum N accumulation for the nonnodulating isoline was significantly lower under irrigated conditions in 1979, but was only numerically lower in 1980. Maximum N accumulations were 115 and 710 mg/plant in 1979 and 355 and 553 mg/plant in 1980 for irrigated and nonirrigated conditions, respectively. Lower N accumulation in the nonnodulating isoline than the nodulating isoline was the result of both lower tissue N concentration and smaller plants (Table 2). The size of this difference was dramatically affected by irrigation and seasonal rainfall patterns. In 1979 dry matter was significantly higher for the nodulating isoline than the nonnodulating isoline with irrigated and nonirrigated conditions, but in 1980 there was no significant difference between isolines. Dry matter was 425% higher in 1980 as compared to 1979 for the irrigated, nonnodulating plants.

Whole-plant N concentrations (mean for all sampling dates) for the nonnodulating isoline was 20.0 and 26.7 $g \cdot Kg_T^-$ in 1979 and 14.2 and 16.1 $g \cdot Kg_T^-$ in 1980 for irrigated and nonirrigated conditions, respectively. Leaching and denitrification of soil NO_3^- probably caused the low N concentration for the irrigated, nonnodulating cultivar in 1979. Nitrogen concentration (mean for all sampling dates) for the nodulating isoline was 30.9 and 31.5 $g \cdot Kg_T^-$ in 1979 and 25.7 and 27.6 $g \cdot Kg_T^-$ in 1980 for irrigated and nonirrigated conditions, respectively. Lower N concentration for all treatments in 1980 was probably due to a dilution effect caused by larger plants than in 1979.

Root development was not determined in this study, however, the literature suggests that it would be similar for both isolines within each respective water treatment (Weber, 1966a, 1966b; Nelson and Weaver, 1980). Within the limits of this assumption, fixed N can be estimated from differences in N accumulation between the nodulating and nonnodulating isolines.

Estimates of total N fixed based on total plant N content was 1120 ± 16% and 862 ± 25% mg N/plant in 1979 and 1120 ± 13% and 846 ± 30% mg N/plant in 1980 for irrigated and nonirrigated conditions, respectively. These values are probably low since the N content of fallen leaves was not determined. Fixation by the nodulating isoline was estimated to account for 91% ± 3% and 55% ± 6% of the total N accumulation in 1979 and 76% ± 5% and 60% ± 12% in 1980 for irrigated and nonirrigated conditions, respectively. Although irrigation increased the contribution of fixed N, it did not greatly increase the total plant N content.

Nodulation, Fixation, and Yield

Results presented in this subsection are intended to partially characterize the status of N fixation under which the previously discussed partitionings of fixed and soil-supplied N were obtained.

Nodulation patterns were significantly affected by irrigation in 1980 (Table 3). Water-stressed soybean had significantly fewer nodules than the irrigated plants during late pod development (113 DAP). Mahler and Wollum (1981) also reported similar trends for the

Table 1. Total N content of soybean tops on four selected dates as affected by nodulation and irrigation in 1979 and 1980.

Days after planting	N Content (mg/plant)				
	Irrigated		Nonirrigated		
	Lee	Lee NN	Lee	Lee NN	LSD (0.05)
			1979		
38	38	35	45	62	35
73	365	107	337	603	201
90	680	115	452	376	172
122	1240	93	1570	710	334
			1980		
49	300	146	562	181	270
58	435	152	564	231	313
93	1470	230	1400	553	739
113	1320	355	871	362	444

Table 2. Plant weight of soybean tops on four selected dates as affected by nodulation and irrigation in 1979 and 1980.

Days after planting	Plant weight (g/plant)				
	Irrigated		Nonirrigated		
	Lee	Lee NN	Lee	Lee NN	LSD (0.05)
			1979		
38	1.1	1.1	1.2	1.8	1.2
73	13.1	6.2	12.3	21.8	9.5
90	24.7	6.1	15.6	16.3	7.2
122	37.0	7.8	49.0	33.1	14.0
			1980		
49	11.6	7.9	19.9	8.3	10.0
58	14.2	8.1	17.1	12.3	11.5
93	61.5	25.2	57.0	46.5	33.1
113	59.6	34.3	35.5	30.9	35.3

Table 3. Nodule number, weight, specific activity, and total C_2H_2-reducing activity of Lee soybean as affected by irrigation at various dates after planting in 1980.

Days after planting	Lee		
	Irrigated	Nonirrigated	LSD (0.05)
	Number of nodules/plant		
58	11	15	
93	53	27	
113	119	36	38
	Nodule fresh weight (g/plant)		
58	0.23	0.27	
93	0.98	0.44	
113	1.55	0.43	0.96
	Specific activity (μmoles C_2H_4/gram nodule fresh wt/h)		
58	11.3	9.3	
93	7.8	4.1	
113	3.2	0.5	5.8
	C_2H_2-reducing activity (μmoles C_2H_4/plant/h)		
58	2.6	2.5	
93	7.6	1.8	
113	4.9	0.2	4.2

Table 4. Yield of nodulating and non-nodulating Lee soybean grown with and without irrigation.

Water treatment	Lee	Lee NN	LSD (0.05)
	t/ha		
	1979		
Irrigated	1.79	0.40	
Nonirrigated	1.65	1.10	0.22
	1980		
Irrigated	2.8	1.19	
Nonirrigated	1.4	0.90	0.20

early growing season. The highest number of nodules occurred during the late pod stage when maximum demand existed for N. Total nodule fresh weight (Table 3) followed the same trend as nodule number. Specific nodule weight ranged from 12 to 20 mg/nodule and was unaffected by irrigation.

Specific C_2H_2-reducing activity (μmoles C_2H_4/gram nodule/h) was not significantly different between water treatments (Table 3). Specific activity decreased throughout the growing season under both irrigated and nonirrigated conditions. Nelson and Weaver (1980) reported similar trends. Total C_2H_2-reducing activity (μ moles C_2H_4/plant/h) was significantly higher with irrigation during the early and late pod development stage (Table 3). Total C_2H_2-reducing activity was also higher during the pod development stage as compared to the flowering stage under irrigation, but decreased during the pod development stage for nonirrigated soybean. Although specific C_2H_2-reducing activity decreased throughout the growing season, nodule biomass increased at a rate which actually resulted in higher total C_2H_2-reducing activity under irrigated conditions. Nelson and Weaver (1980) also reported that total C_2H_2-reducing activity increased throughout the growing season.

In 1979 irrigation had no effect on the yield of the nodulating soybean, but significantly decreased the yields of the nonnodulating soybean by 0.69 t/ha (Table 4). Nitrogen fixation resulted in a 1.39 and a 0.55 t/ha increase in yield under irrigated and nonirrigated conditions, respectively. Irrigation significantly increased seed yields in 1980 for both isolines. Nitrogen fixation resulted in a 1.58 and a 0.49 t/ha increase in yield for irrigated and nonirrigated treatments, respectively. Over the 2-year period, the N fixation ability allowed an increased yield of 1.49 and .52 t/ha under irrigated and nonirrigated treatments, respectively. These data indicate that performances of *Rhizobium japonicum* strains are likely to be more important under irrigated conditions for determinate soybean grown on soils in this region.

The results from this study show that: 1) fixation normally provides greater than 50% of accumulated N and may provide as high as 90% of the accumulated N; 2) irrigation and rainfall patterns greatly affect N accumulation and the percentage of N supplied from fixation; and 3) the difference in yield between nodulating and non-nodulating soybean was nearly 1 t/ha greater under irrigated than nonirrigated conditions.

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